State of California

Business Transportation and Housing Agency

Memorandum

To: ALL DESIGN BRANCHES

Date: March 20, 2001

File:

From: **DEPARTMENT OF TRANSPORTATION**
ENGINEERING SERVICE CENTER
Division of Structure Design, Mail Station 9 4/11G

Subject: Alternative Method for Seismic Modeling of Abutments

Linear elastic dynamic analysis models (STRUDL) have traditionally been used at Caltrans to estimate the seismic displacement demands on our bridge systems. The time and effort involved in performing more sophisticated non-linear analysis is substantial and has been reserved for non-standard bridges.

The current linear models include elastic springs intended to represent the abutment stiffness. The value of performing a number of iterations to determine the abutment stiffness (as outlined in Bridge Design Aids, Page 14-4, last paragraph) has been debated in the past. It should not be assumed that linear models will necessarily produce a better solution of the highly non-linear abutment response simply because they have been refined through this iterative process.

The purpose of this memo is to allow the design engineer to consider the new abutment modeling procedure documented in "Seismic Design of Abutments for Ordinary Standard Bridges" as an ACCEPTABLE ALTERNATIVE to our current practice.

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Attachment

SEISMIC DESIGN OF ABUTMENTS
FOR ORDINARY STANDARD BRIDGES

INTRODUCTION

This memorandum outlines Caltrans' seismic design policy, philosophy, performance and design criteria for the abutments of ordinary bridges. See Memo To Designer (MTD) 20-1 "Seismic Design Methodology" for the definition and performance criteria for ordinary bridges. The performance level and design criteria for the abutments of important bridges shall be addressed in the project specific seismic design criteria. See MTD 20-11 "Establishing Bridge Seismic Design Criteria" for information on developing project specific seismic design criteria.

SEISMIC DESIGN POLICY

Abutments are generally designed and detailed for service loads, and evaluated for seismic performance. Abutments must have enough strength to support the superstructure's self weight and provide adequate seat width to prevent unseating of the superstructure during the Maximum Credible Earthquake (MCE).

SEISMIC DESIGN PHILOSOPHY

The following concepts collectively make up Caltrans' design philosophy for abutments. Bridge abutments designed and detailed according to this philosophy have performed well during past earthquakes and have satisfied the seismic performance criteria.

- **Abutment need to satisfy the seismic performance criteria for the safety-evaluation ground motion specified in MTD 20-1 "Seismic Design Methodology".**

  An explicit functional evaluation of abutment performance for lessor earthquakes is not required.

- **A realistic estimate of abutment participation shall be included in the bridge seismic demand and capacity assessments.**

  The impact of the abutment on the overall response of the bridge will depend upon the abutment's load-transfer mechanism, effective stiffness, level of expected damage, as well as the strength of the abutment-soil system and the bridge's structural configuration.

SEISMIC DESIGN OF ABUTMENTS
FOR ORDINARY STANDARD BRIDGES

- **It is not practical or cost effective to design abutments to remain entirely free of damage when they are subjected to ground motion from large earthquakes.**

  Attempts shall be made to design and detail the abutment to concentrate seismic damage at selected locations that are easily repairable and protect vulnerable abutment components from inelastic response.

- **It is unlikely that inelastic response of the abutment foundation during earthquake ground motions will be the sole cause of an abutment collapse.**

  It is difficult to completely eliminate the possibility of inelastic response in the abutment foundation because of the uncertainty in predicting the ultimate strength of sacrificial components and the elastic capacity of the abutment foundation. However, by designing the foundation for the upper bound strength of the sacrificial components coupled with the inherent vertical and horizontal capacity of typical abutment foundations makes catastrophic failure of the abutment attributed solely to inelastic response of the foundation unlikely.

- **Skewed abutments are highly vulnerable to damage from large earthquakes.**

  It is desirable to reduce abutment skew angles, even at the expense of increasing the bridge length, within reason. Skew angles over 20° may significantly affect seismic response of the bridg, and shall be considered when assessing the seismic demand and the reliable available capacity.

- **The abutment's contribution to the damping of bridge energy shall be considered.**

  Short bridges with low skew angles and abutments designed for sustained soil mobilization in both the longitudinal and transverse direction, likely possess equivalent viscous damping ratios larger than the 5% typically selected for developing response spectra. Seismic force levels for these types of bridges may be reduced to account for greater equivalent viscous damping capacity. See the Caltrans Seismic Design Criteria (SDC) for the force reduction equation.

ABUTMENT TYPES AND DESIRED SEISMIC PERFORMANCE

Seat Abutments

Short seat abutments support the bridge superstructure on a horizontal seat. Typically short seat abutments include a backwall which retains the approach fill material above the seat. The backwall is considered to be sacrificial during MCE response. The backwall is intended to break off and mobilize the longitudinal resistance of the approach fill while limiting the demands transmitted to the lower portion of the abutment.

Seat abutments typically have shear keys that resist transverse movement under service loads and moderate earthquakes. The shear keys are designed to fail during larger earthquakes, isolating the abutment foundation from large forces and deformations that would likely induce inelastic response.

The shear keys for abutments supported on spread footings may be designed to transmit the seismic forces to footing if the soil surrounding the abutment will resist the seismic demand at displacements that will not compromise the abutments functionality.

High cantilever seat abutments are similar to short seat abutments except that the abutment seat is supported on a narrow stem that retains the approach fill material. The abutment stem shall have sufficient nominal strength to resist the demands imparted by the backwall as it reaches its ultimate capacity.

Diaphragm Abutments

Diaphragm abutments consist of an end diaphragm that is cast integral with the superstructure and the abutment stem. The diaphragm can be supported on piles, spread footings or can be isolated from the foundation by bearing pads. The diaphragm retains the abutment approach fill under service conditions, and mobilizes the fill longitudinally during seismic response. The longitudinal resistance that can be relied on is limited to the lessor of the passive capacity of the approach fill, the capacity of the diaphragm, or the capacity of the piles.

The transverse capacity of a diaphragm abutment is typically governed by the lateral capacity of the foundation. The transverse seismic demand should not govern the number of piles required because the increase in capacity provided by additional piles is small compared to the ultimate resistance generated by the diaphragm moving through the surrounding soil.

Diaphragm abutments typically provide sustained soil mobilization when the abutment engages the backfill longitudinally and transversely. This type of response can significantly increase the bridge’s energy damping capacity.

Wingwalls

Wingwalls are primarily designed to retain the approach fill parallel to the centerline of the bridge. Typically wingwalls are cantilevered from the back of the abutment or supported at the end by a spread footing or pile. Research [Avila] has shown that cantilever wingwalls are very flexible and will not contribute significantly to the transverse capacity or stiffness of the abutment at the anticipated MCE displacements and should conservatively be ignored.

Strutted Abutments

Strutted abutments consist of an abutment stem similar to a retaining wall and the superstructure element that resists earth pressure and lateral displacement at the top of the abutment generated by the backfill and the live load. The superstructure acts as a strut and transfers the earth pressure force through axial load to the opposite abutment. The standard strutted abutment shown on Bridge Standard Detail Sheet XS 22-1 has not been explicitly designed for seismic response. The suitability of strutted abutments for a particular application shall be determined at the Type Selection meeting.

Bent Abutments

Bent abutments incorporate ductile elements to resist the longitudinal and transverse seismic demands. Bent abutments provide a higher level of performance at a higher cost and are considered non-standard components. Their performance and design requirements shall be addressed in project specific criteria.

SEISMIC DESIGN CRITERIA

The elastic response analysis must include realistic predictions for abutment stiffness in order to determine realistic displacement amplitudes at the abutments and the bents or piers.

We assume, based on the equal displacement observation, that linear elastic dynamic analysis can reasonably predict inelastic displacement demands. However, the forces predicted from the elastic analysis may differ considerably from the actual forces since elastic analysis cannot account for bent ductility or the nonlinear hysteric force–deformation response of the backwall or diaphragm and the approach fill. Nonlinear abutment response is generated by complex mechanisms such as opening and closing of the expansion gap, failure of the backwall, mobilization of the approach fill, shear key failure, and soil gapping caused by displacement reversals.

SEISMIC DESIGN OF ABUTMENTS
FOR ORDINARY STANDARD BRIDGES

Longitudinal Abutment Performance

The following procedure can be used in lieu of a nonlinear analysis to assess the abutment's contribution to the overall longitudinal response of the bridge. The designer determines an effective longitudinal abutment stiffness for the elastic demand model, examines the displacement results, and decides if the effective stiffness is appropriate or needs to be adjusted based on the displacement results of the elastic analysis.

1. Calculate the Effective Abutment Area

The effective abutment area for calculating the ultimate longitudinal force capacity of an abutment is determined as follows:

For seat abutments the backwall is typically designed to break off in order to protect the foundation from inelastic action, the area considered effective for mobilizing the backfill longitudinally is equal to the area of the backwall.

For diaphragm abutments the entire diaphragm, above and below the soffit is typically designed to engage the backfill immediately when the bridge is displaced longitudinally, the effective abutment area is equal to the entire area of the diaphragm. If the diaphragm has not been designed to resist the passive earth pressure exerted by the abutment backfill, the effective abutment area is limited to the portion of the diaphragm above the soffit of the girders.

$$A_e = \begin{cases} h_{bw} \times w_{bw} & \text{Seat Abutments} \\ h_{dia} \times w_{dia} & \text{Diaphragm Abutments} \end{cases} \qquad (1)$$

where: $h_{dia} = h_{dia}^{*} =$ Effective height when the diaphragm is not designed for seismic soil resistance

$h_{dia} = h_{dia}^{**} =$ Effective height when the diaphragm is designed for seismic soil resistance

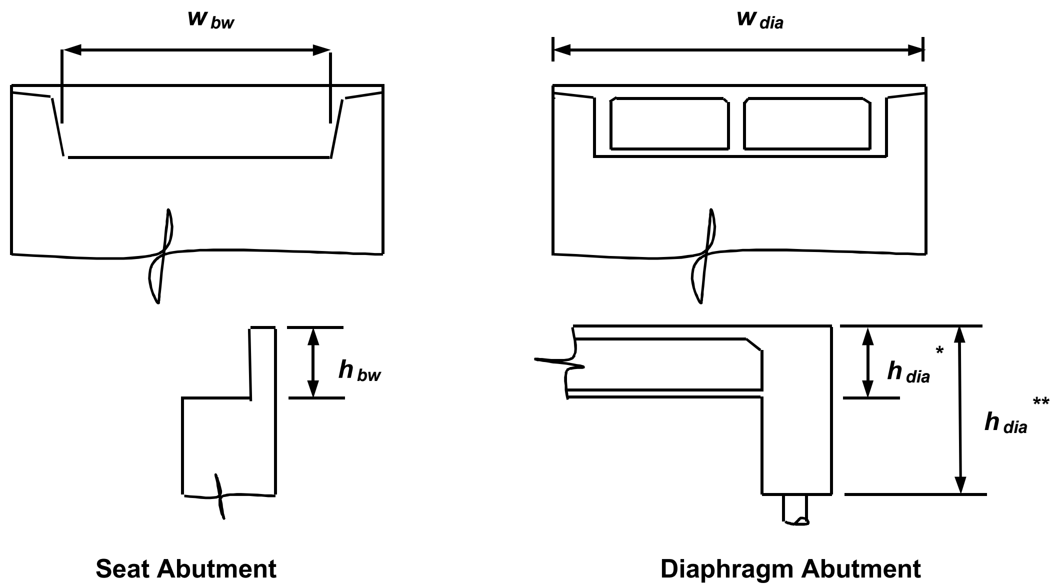

Figure 1 Effective Abutment Area

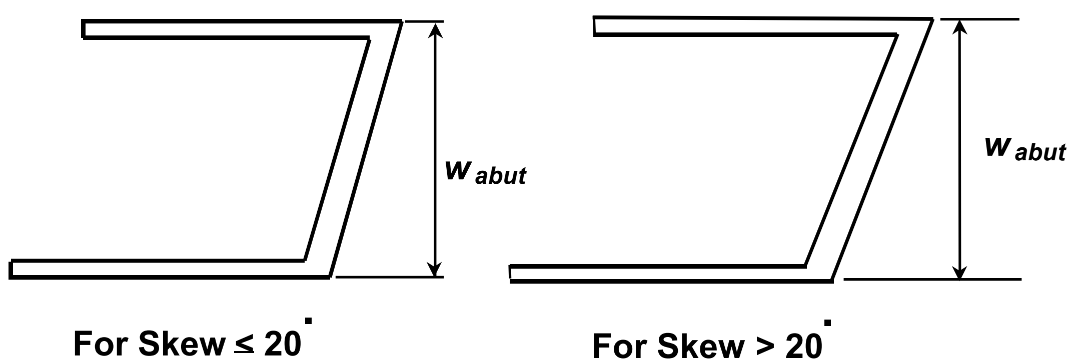

Figure 2 Effective Abutment Width For Skewed Bridges

2. Establish the Maximum Idealized Passive Resistance[1]

$$P_{bw}\ or\ P_{dia} = \begin{cases} A_e \times 5.0\ ksf \times (\dfrac{h_{bw}\ or\ h_{dia}}{5.5}) & (ft, kip) \\ A_e \times 239\ kPa \times (\dfrac{h_{bw}\ or\ h_{dia}}{1.7}) & (m, kN) \end{cases} \tag{2}$$

This equation has been deleted (3)

3. Establish the idealized initial backwall stiffness K_i.

One method for approximating the initial backwall stiffness is based on the balanced area method. Figure 3 illustrates the elasto-plastic idealization of the abutment force deflection curve from the UCD test [Maroney] determined by the balanced area method.

The initial backwall stiffness is dependent on the rigidity of the backwall and the geotechnical characteristics of the backfill material. Idealization of the data from the UC Davis abutment test suggests an initial longitudinal abutment stiffness on the order of $K_i \approx 20\ kip/in/ft$ $(11.49\ kN/mm/m)$ see footnote[2]. Generally the initial stiffness of cohesionless soils is larger than the initial stiffness observed for cohesive soils. The total longitudinal abutment stiffness can be estimated by equation 4.

$$K_{abut} = \begin{cases} K_i \times w \times \left(\dfrac{h}{5.5}\right) & \text{U.S. units} \\ K_i \times w \times \left(\dfrac{h}{1.7}\right) & \text{S.I. units} \end{cases} \tag{4}$$

Where: w = The width of the backwall or the diaphragm for seat and diaphragm abutments respectively

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[1] The value for backwall passive pressure of 5.0 ksf (239 kPa) is based on the ultimate static force developed in the full scale abutment testing conducted at UC Davis [Maroney, 1995]. The height reduction factor, $h/5.5\ ft \left(h/1.7\ m\right)$ is based on the height of the UC Davis abutment specimen 5.5 ft (1.7 m).

[2]Typically abutment stiffness is normalized by the width of the abutment. The abutment test specimen was 10 feet (3 m) wide.

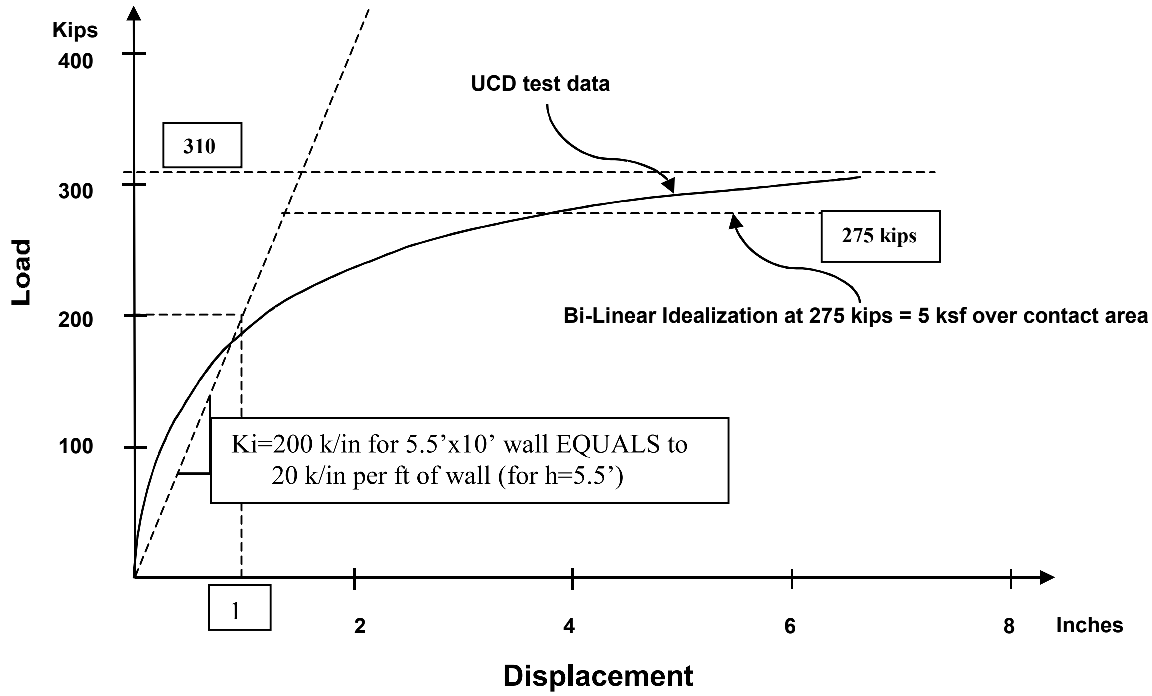

Figure 3 Estimated Bi-linear Abutment Stiffness (UCD test)

4. Calculate Effective Abutment Stiffness and Effective Displacement.

Using the passive resistance described in step 2 establish the force level (P_{bw} or P_{dia}) in Figure 4. Establish the starting point on the horizontal axis at Δ_{gap} or origin for seat and diaphragm type abutments, respectively. For seat abutments use the most probable expansion gap, Δ_{gap} between the superstructure and the backwall based on the anticipated shortening and thermal movement. For diaphragm abutments $\Delta_{gap} = 0$. Draw a line from the starting point with the slope of K_i to intersect the P_{bw} or P_{dia} line. A line through the origin, as shown in Figure 4, defines the effective abutment stiffness (K_{eff}). The effective displacement Δ_{eff} is also shown in Figure 4.

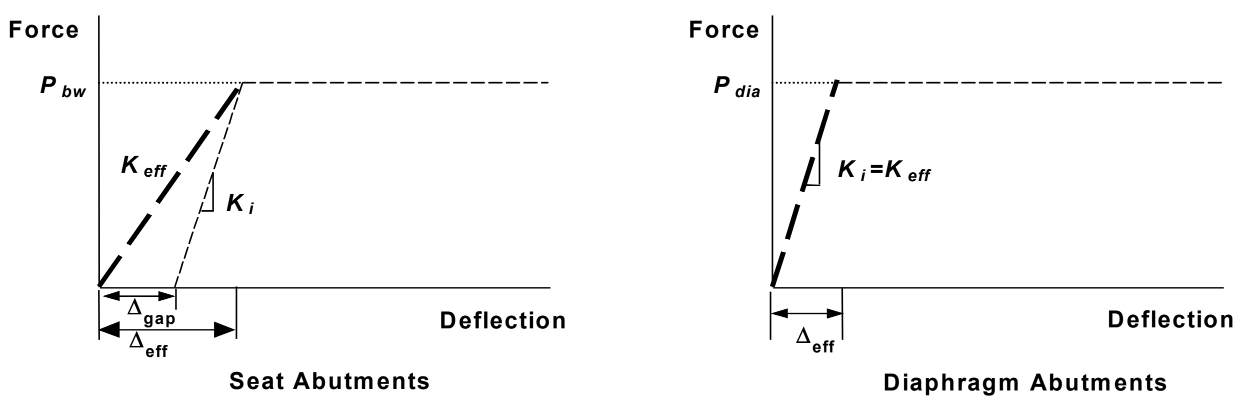

Figure 4 Effective Stiffness for Abutments

5. Incorporate Effective Longitudinal Abutment Stiffness in the Elastic Demand Assessment Model.
Use the effective longitudinal abutment stiffness K_{eff} calculated in step 4 in the elastic model. It is not necessary to iterate the abutment stiffness and re-run the elastic analysis to reach convergence between the abutment forces and displacements because the limitations of elastic analysis prevent accurate prediction of the actual abutment force demands.

6. Calculate the Abutment Displacement Coefficient R_A
Compare the longitudinal displacement at the abutment derived from the elastic analysis to the effective displacement derived in step 4. The ratio of these displacements R_A is calculated by equation 5.

$$R_A = \Delta_D / \Delta_{eff} \tag{5}$$

where: Δ_D = The longitudinal displacement demand at the abutment from elastic analysis
Δ_{eff} = The effective longitudinal abutment displacement calculated in step 4.

The magnitude of R_A indicates the participation level of the abutment in the overall response of the bridge.

If $R_A \leq 2$ The elastic response is dominated by the abutments. Most likely the abutment stiffness is large relative to the stiffness of the bents or piers. The column displacement demands generated by the linear elastic model can be used directly to determine the displacement demand and capacity assessment of the bents or piers.

If $R_A \geq 4$ The elastic model is insensitive to the abutment stiffness. Most likely the abutment contribution to the overall bridge response is small and the abutments are insignificant to the longitudinal seismic performance. The bents and piers will likely sustain significant damage under seismic attack and it is not reasonable to rely on the simplistic abutment capacity assessment to reduce the global displacement demand at the bents. Reduce the effective abutment stiffness K_{eff} in the elastic model to a minimum residual stiffness K_{res} defined by equation (6), and re-run the elastic analysis for revised column displacements. K_{res} accounts for residual longitudinal stiffness after the backwall or the diaphragm has failed. The residual spring has no relevance to the actual stiffness provided by the failed backwall or diaphragm but should suppress unrealistic response modes associated with a completely released end condition.

$$K_{res} \approx 0.1 * K_{eff} \qquad (6)$$

If $2 \leq R_A \leq 4$ The bridge response predicted by the elastic model may be sensitive to the abutment stiffness. The initial estimate of the effective longitudinal abutment stiffness was too high and is not consistent with the level of displacement produced by the model. Reduce the abutment stiffness in the elastic model by interpolating an effective abutment stiffness between K_{eff} and the residual stiffness K_{res} based on the R_A value. Re-run the elastic analysis to obtain revised column displacements.

7. Calculate The Minimum Required Seat Width

The seat width for seat abutments shall be large enough to accommodate the anticipated thermal movement, prestress shortening, creep, shrinkage, and the relative longitudinal earthquake displacement. The seat width normal to the centerline of bearing shall be the larger of the value calculated by either equation (7) but not less than 30 inches (750 mm).

$$N_A \geq \begin{cases} \left(\Delta_{p/s} + \Delta_{cr+sh} + \Delta_{temp} + \Delta_{eq} + 4\right) & \text{(in)} \\ \left(\Delta_{p/s} + \Delta_{cr+sh} + \Delta_{temp} + \Delta_{eq} + 100\right) & \text{(mm)} \end{cases} \qquad (7)$$

N_A = Abutment seat width normal to the centerline of bearing

$\Delta_{p/s}$ = Displacement attributed to pre-stress shortening

Δ_{cr+sh} = Displacement attributed to creep and shrinkage

Δ_{temp} = Displacement attributed to thermal expansion and contraction

Δ_{eq} = The largest relative earthquake displacement between the superstructure and the abutment calculated by either the global or stand-alone analysis

The "Seat Width" requirements due to the service load considerations (Caltrans Bridge Design Specifications and AASHTO requirements) shall also be met.

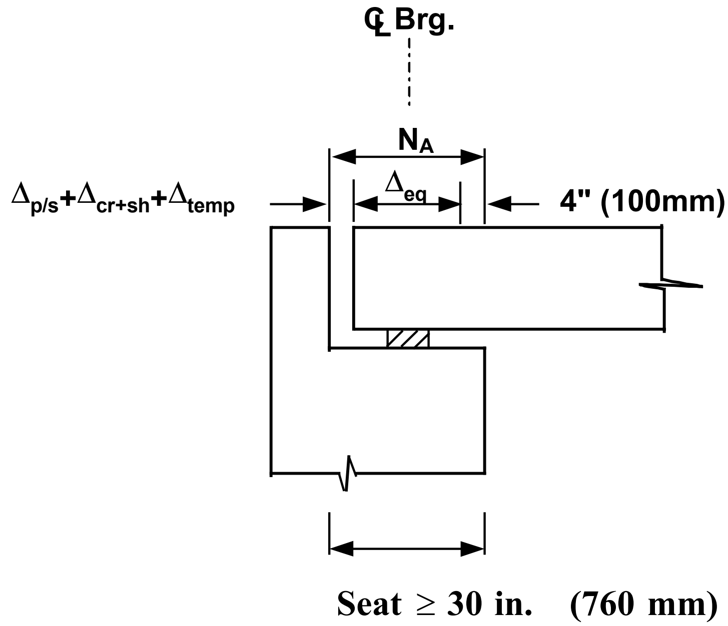

Figure 5 Abutment Seat Width Requirements

Transverse Abutment Performance

Seat Abutments

Seat abutments are designed to resist transverse service load and moderate earthquake demands elastically. Typically seat abutments are not considered effective for resisting MCE demands because linear analysis cannot capture the inelastic response of the shear keys, wingwalls, or piles. The designer must account for the force-deflection characteristics of each element utilized to resist MCE demands.

The abutment should not be completely released in the analytical model. It is reasonable to assume that the friction between the super-structure and the shear keys will continue to resist transverse movement. A nominal transverse spring, $K_{nom} \approx 120$ k/ft, is recommended. The nominal spring has no relevance to the actual residual stiffness provided by the failed shear key but should suppress unrealistic response modes associated with a completely released end condition. This approach is believed to be conservative since larger amounts of lateral resistance at the abutments that are not captured by the nominal spring will only reduce the transverse displacement demands at the bents.

Shear Keys

Shear keys are designed to limit the amount of force transmitted below the abutment seat under large earthquakes, protecting the piles from inelastic behavior. Shear key capacity for seat abutments shall be limited to the smaller of the following[3]:

$$F_{sk} \le \begin{cases} .75 \times \sum V_{pile} & \sum V_{pile} = \text{Sum of the lateral pile capacity} \\ 0.3 \times P_{dl}^{\sup} & P_{dl}^{\sup} = \text{Axial dead load reaction at the abutment} \end{cases} \tag{9}$$

External Shear Keys

The length of the deck overhang, the slope of the exterior girder, and the width of the abutment seat usually dictate the size of the external shear keys. The aspect ratio of external shear keys sized in this manner may elicit short shear-span member behavior. Shear and flexure modes of failure associated with short shear-span members shall be considered in the shear key design.

Internal Shear Keys

Wide bridges may require internal shear keys to resist the transverse demands from service loads and moderate earthquakes. Internal shear keys shall only be used when absolutely necessary because they are susceptible to damage if the superstructure rotates or displaces and are difficult to inspect and repair. A large enough gap shall be placed between the end diaphragm and the internal key to minimize the risk of the keys binding due to thermal, shrinkage or service level deformations.

Diaphragm Abutments

Diaphragm abutments, like seat abutments, will most likely undergo nonlinear action during large earthquakes. However, the transverse stiffness can conservatively be estimated as the stiffness of the piles ignoring the wingwalls. Typically the lateral stiffness of standard piles is assumed to be 40 kips/in (7.0 kN/mm) per pile at 1 in. (25 mm) of displacement. This is a reasonable rule-of-thumb value for stiffness considering the many

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[3] Abutments requiring a large number of piles to satisfy demands other than seismic can generate excessive key capacity that is unnecessary for moderate demand levels. Therefore, a moderate earthquake acceleration limit was adopted. The 0.3 $P_{dl}^{\sup}$ shear key capacity was selected as reasonable upper bound acceleration for a "moderate" earthquake. The designer should verify that this acceleration is reasonable considering the seismicity or any unique parameters at a particular bridge location.

The contribution of typical wingwalls on the lateral capacity of the abutments has been conservatively ignored because of the inability to accurately assess their effectiveness. This may lead to shear keys that fail at demands significantly less than the true lateral capacity of the rest of the abutment.

assumptions made to simplify the complex behavior of the abutment. Higher stiffness and capacity values can be used if they are justified by site-specific soil-pile interaction analysis.

Wingwalls

Analytical studies have shown that cantilever wingwalls less than 18 in. (450 mm) thick cannot mobilize soil resistance beyond 5 feet (1.5 m) from the point of support [ATC]. Experimental studies have shown that cantilever wingwalls may attract as little as 15% of the lateral load applied to the abutment even at deformations that caused significant inelastic action in the piles [Avila]. In light of these studies, it is recommended that the contribution of the wingwalls to the lateral capacity of the abutment be conservatively ignored.

The designer must demonstrate there is a reliable force-deformation relationship for the wingwall and wingwall/abutment connection if he/she elects to include the wingwall contribution to the abutment's transverse capacity. In addition, the designer should keep in mind that the wingwall will respond in parallel with other abutment components and the individual component stiffness must be considered when determining available capacity at a given lateral displacement. If all these conditions are met, the transverse capacity may be engineered using the procedure for the longitudinal direction previously outlined.

Skewed Abutments – Seat Width

Bridges with skew abutments have a tendency for increased displacements at the acute corner. One possible movement scenario is shown in Figure 6, where rotation of the bridge is the result of the impact at the obtuse corners. Also, the longitudinal movement of the bridge may open up gaps between the bridge and the abutment back walls, creating rotation opportunities for the bridge and loss of the seat at the acute corner.

The likelihood of unseating is dependent on many parameters including the severity of skew, bridge length to width ratio, direction of the ground motion, and the longitudinal displacement of the backwall. The potential for unseating at the acute corner can be reduced by increasing the seat width. An upper bound estimate for the seat width may be conservatively estimated by Δ_A the displacement measured perpendicular to the abutment seat when the bent adjacent to the abutment is displaced to its ultimate displacement demand determined by pushover analysis. See Figure 7. It must be noted that the phenomenon described in Figure 7 is conservative and it is only presented as a guide until better procedures are developed.

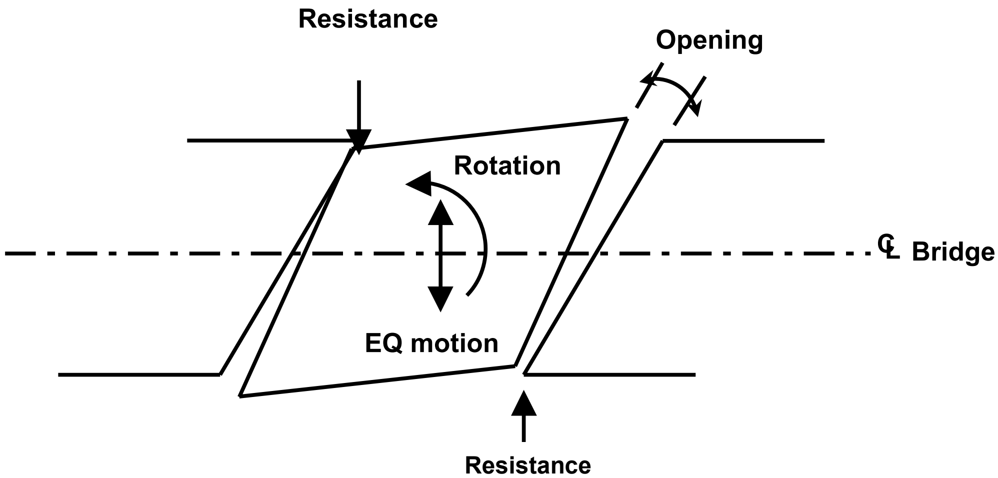

Figure 6 Skewed Bridge Rotation

Skewed Abutments – Shear Keys

The capacity of sacrificial shear keys shall be increased 0.1g per 10° of skew exceeding 20° (see equation 10). The larger shear capacity will inhibit the superstructure's tendency to rotate and reduce the potential for shear key damage during moderate earthquakes.

For skews > 20°:

$$F_{sk} \geq \left[0.3 + 0.01 \times (s - 20^{\circ})\right] \times P_{dl}^{\sup} \tag{10}$$

As the abutment skew angle increases, the shear key strength and seat width requirements for non-ductile shear keys become impractical. In these situations, designers are encouraged to consider ductile abutment systems that actively resist the abutment demands.

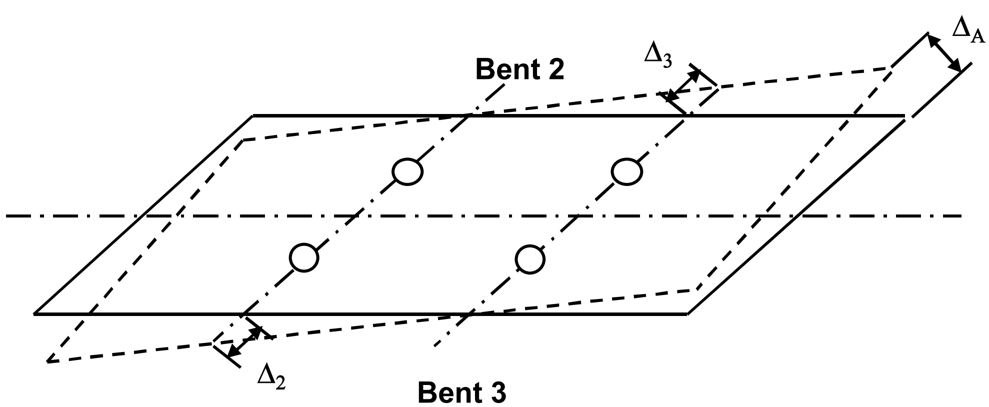

Figure 7 Upperbound Displacements For Skewed Abutments

ANALYTICAL MODELING RECOMMENDATIONS

Longitudinal Analysis:

Linear elastic dynamic computer models (STRUDL) may be required to estimate the displacement demands if the "Equivalent Static" models cannot produce reasonable results, as described earlier in this document. The dynamic response of the bridge varies depending on which way the bridge is moving. Two global models are normally required to capture this phenomenon. The compression model represents the bridge moving toward the abutment and the passive resistance of the soil is completely mobilized. The tension model represents the structure moving away from the abutment or soil and little or no soil resistance is mobilized.

The truss element is available to model the abutment stiffness with linear elastic dynamic analyses. However, the truss element possesses the same axial stiffness when it is subjected to tension or compression. Therefore, when the bridge is moving toward an abutment (compression model), the total structure stiffness would be too high if the full passive resistance was used at both abutments, so an approximation of one-half the total stiffness is usually allocated to each abutment, see Figure 8. The longitudinal displacement demands predicted by the compression model is acceptable, however, the force reported by the computer at each abutment must be doubled. Please note that the force obtained by using the displacement demand at the abutment and the original abutment stiffness should not be doubled.

If the relative stiffness of the two abutments differs by more than ***25 %*** two models are required where the full stiffness of each abutment is alternately assigned with the other abutment stiffness set to zero.

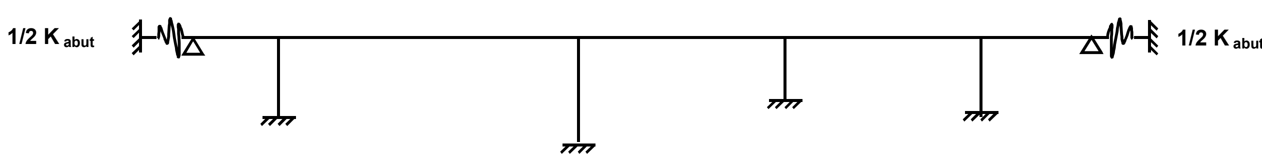

Figure 8 Distribution of Longitudinal Abutment Stiffness in the Compression Model

Longitudinal Analysis: special case of "Two Span" Bridges

- Two span bridges have some unique characteristics that should be considered when interpreting their analytical results. A key parameter in determining the significance of the abutments to the bridge's dynamic performance is the ratio of the abutment stiffness to total system stiffness. As the number of bents increases the abutments impact on the overall dynamic response will likely diminish. Typically on two span bridges the stiffness attributed to the bent is small compared to the stiffness of the abutments and the analytically derived displacement should be similar to the expected displacement calculated in step 4 of the longitudinal performance procedure, presented earlier.

The longitudinal stiffness value recommended in this memo is significantly lower than previous Caltrans practice and it may lead to more difficulty meeting the ductility requirements for short bridges with typical component sizes used in the past. The intent of Caltrans seismic design methodology is to provide ductility in regions of anticipated high demand and permit greater flexibility in the structure response. Short bridges with short columns will have difficulty meeting the SDC ductility requirements with lower contribution from the abutment. Possible methods for enhancing the ductility of these types of bridges is to reduce the column stiffness resulting in a reduction of the effective stiffness in the longitudinal direction.

Transverse Analysis: special case of "Two Span" Bridges

The general case of "Abutment Transverse Performance" was presented earlier with recommendations on the nominal transverse spring. In the special case of two span bridges (particularly with a single-column bent) one may find instability in the "Linear Elastic Dynamic (STRUDL)" model. This is seen as excessive rotation of the superstructure relative to the abutments. This mode is highly unlikely given the shear keys that are not (and cannot be) quantified properly. The nominal transverse spring values may have to be increased until translation of the span (not rotation) is seen in the transverse analysis.

Modeling Skewed Abutments:

If there is a need to construct linear elastic dynamic model (STRUDL) of a skew bridge one may use the following technique to obtain the displacement demands parallel and perpendicular to the centerline of the skewed abutment bearing.

- Include two space truss members at each abutment to represent the longitudinal and transverse abutment stiffness. The truss members must be aligned parallel and perpendicular to the abutment (see Figure 9).

- Set the truss members' axial stiffness equal to the calculated effective stiffness K_{eff}

$$K_{eff} = \frac{A_t \times E}{L} \tag{11}$$

- A convenient method to set K_{eff} is to set E = 1 ksf (48 kPa) and L = 1 ft. (1 m). A_t is then equal to the calculated abutment stiffness.

- Deflections are then calculated as

$$\Delta_A = \frac{F}{K_{eff}} \tag{12}$$

Seat Width for Skewed Bridges

For bridges with large skews it is desirable to predict the possibility of unseating of the acute corners. The deflection perpendicular to the abutment at the corners may be calculated with the following procedure:

- Include two space frame members at each abutment that extend from the bridge centerline to the edge of the abutment. These members need to be stiff enough that their deflections are minimal.

- At the ends of the stiff members, attach a truss member perpendicular to the abutment. The other end of the truss member will be attached to ground. These members need to be soft enough that they don't affect overall system response. See Figure 10.

- Deflections are then calculated as:

$$\Delta_A = \frac{F}{K} \tag{13}$$

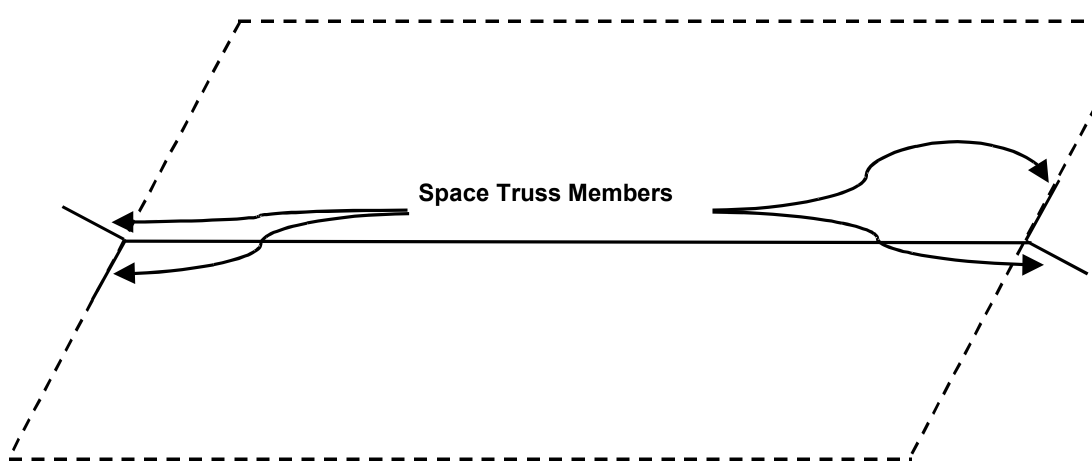

Figure 9 Abutment Space Truss Members For Linear Elastic Model

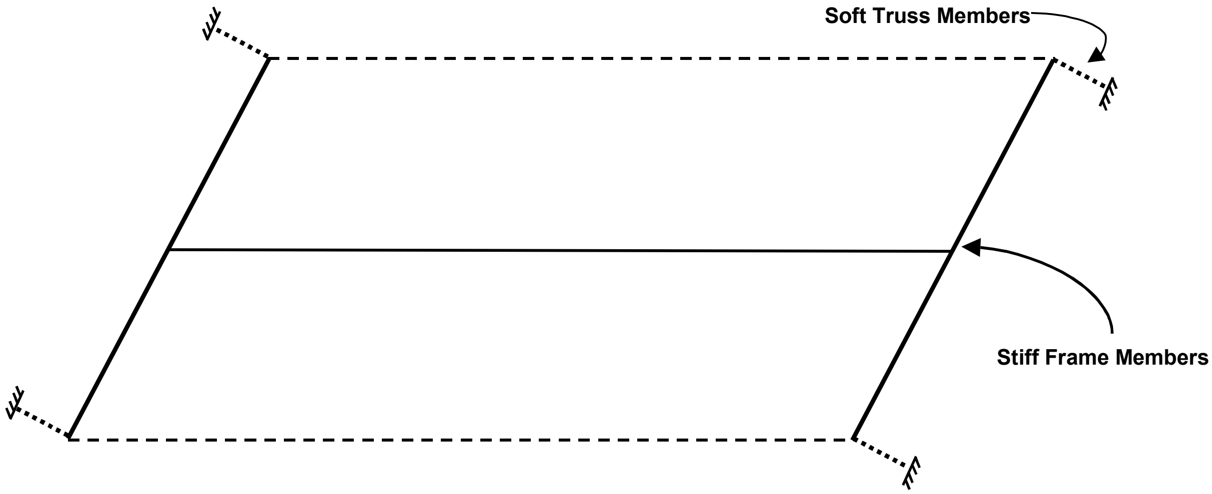

Figure 10 Space Truss Members For Capturing Displacements at Skewed Abutments

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3. ATC 32, "Improved Seismic Design Criteria for California Bridges: Provisional Recommendations", 1996.
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